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Calibration of the Artemis Source and Receiving Array on the Mission Capistrano

[Unclassified Title]

M. Flato

Systems Engineering Staff
Acoustics Division

December 1973

NAVAL RESEARCH LABORATORY
Washington, D.C.

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(U) Calibration of the ARTEMIS source and receiving array on the MISSION CAPISTRANO was performed in 1970 prior to the termination of the project. Descriptions of the source and receiving system, the tests which were performed, including instrumentation used, and test results are presented. Results include transmitting response of the source from 1 to 100 amperes in the band of interest, fourteen vertical beam patterns, a horizontal on-axis beam pattern and the receiving array sensitivities and array gains.

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ACKNOWLEDGEMENT

(U) The author wishes to acknowledge the following for assistance with the measurements conducted aboard the MISSION CAPISTRANO: Captain Bertil Von Gerber and crew of the MISSION CAPISTRANO; the Welex personnel that operated and maintained the project equipment; Mr. Charles Bobo, Underwater Reference Division, Naval Research Laboratory; Mr. Arthur T. McClinton and Mr. Jack Bright, Acoustics Division, Naval Research Laboratory.

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CALIBRATION OF THE ARTEMIS SOURCE AND RECEIVING ARRAY ON THE MISSION CAPISTRANO

I. INTRODUCTION

(U) A calibration of the Artemis source and receiving array on the MISSION CAPISTRANO was performed in 1970. The last previous source calibration was completed in 1964 by Ferris and Rollins.[1] The source calibration reported herein differs principally from that used by Ferris and Rollins in the method used in separating the source from the measuring hydrophone. Ferris and Rollins measured from a 190 foot boom attached to the source while this calibration was performed by suspending a hydrophone from a small boat tethered 300 feet from the MISSION CAPISTRANO.

(U) The calibration of the source was performed during the engineering trials after the system was overhauled. The operation took place in the Northwest Providence Channel in approximately 3,000 feet of water between 18-20 February 1970. The receiving system response measurements took place in the same area during 10-11 July 1970.

(U) A transmitting response measurement was made of the Artemis array on-axis at currents from 1 to 100 amps. A volume beam pattern for the transmitting array was accomplished from 0° (on-axis) to 180° (backside) azimuthal and ±30° in the vertical. On-axis receiving response calibration was obtained for the hydrophone array attached to the source structure.

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[1] Ferris R. and Rollins, D. R., "Project Artemis Acoustic Source Performance Characteristics" (Confidential Report, Unclassified Title), NRL Report 6534, June 15, 1967.

II. DESCRIPTION OF THE SOURCE AND RECEIVING ARRAY

(U) The source and receiving arrays on the MISSION CAPISTRANO are mounted on the face of a structure 33 feet wide by 50 feet high which is tilted from the vertical by 11°. The source array consists of 1,440 one-foot cube variable-reluctance transmitting elements which are tied together in parallel through a transformer and blocking capacitor arrangement. The blocking capacitors are used because the elements require DC polarizing power. Behind the planar rows of source elements are stacks of compliant squash tubes which provide the pressure release for the source. The tubes are filled with air regulated to a 15 psi differential pressure between the air and water.

(U) The receiving array is composed of two planar arrays, one mounted on the face of the source and the other at the end of six-foot extension arms (1/2 wave length at 400 Hz). Each planar array contains 48 hydrophones arranged in six vertical strings of eight hydrophones each. The spacing between rows and hydrophones in each row is six feet or 1/2 wave length at 400 Hz. The receive sensitivity of each hydrophone is approximately -89 db re one volt at one microbar.[2] The six strings of hydrophones that make up the planar array on the face of the source are paralleled together and connected to a shielded twisted pair of conductors in the instrumentation cable. The six strings of hydrophones that make up the extended planar array are also paralleled together and connected to another pair of shielded twisted conductors. The instrumentation cable is a 2400 foot armored cable that contains 19 shielded twisted pairs of conductors.

(2) USRD Calibration Report Nos. 3125 and 3126, Repair and Calibration of 2ZS Hydrophones, 22 June 1970.

III. INSTRUMENTATION

(U) The block diagrams for the transmit and receive calibrations are as shown in Figures 1 and 2, respectively. The transmit instrumentation consists of the basic transmitting system on the MISSION CAPISTRANO and additional equipment to receive and record the signals at a known distance away. The receive calibration instrumentation utilizes the receive system installed on the ship and additional equipment to transmit from a source suspended from a small boat.

(U) The electronic programmer which normally controls the operation of the power amplifier was used during the calibration. The programmer produced an external pulse simultaneously with the signal output to trigger an oscilloscope sweep. The travel time between signal emission at the source and its reception at the hydrophone was measured on the oscilloscope calibrated sweep to measure travel time. This travel time measurement was converted into distance by computation using an average sound speed of 5,000 feet per second. No attempt was made to be more precise by using actual sound speed measurements in computing travel time since it could change the determination of distance by only a negligible amount.

(U) An additional hydrophone was attached near the physical center of each plane of the receiving array and another hydrophone was suspended 300 feet below the source. These hydrophones were added so that a comparison of receive signals could be made between a plane of hydrophones and a single hydrophone on that plane and a plane of hydrophones and the suspended hydrophone.

(U) During the calibration of the system each string in both the face and extended planes was brought up separately through individual pairs of conductors in the

instrumentation cable. This was accomplished by eliminating the top hydrophone in each string and connecting the string at that point to a shielded twisted pair in the instrumentation cable. The modification reduced each plane of the receive array from 48 to 42 hydrophones which will not affect the overall receive response greatly. Resistance measurements were made on the receiving array at the ship's end of the instrumentation cable before and after submergence of the array. Resistance between the twisted pairs and each conductor to ground were recorded.

IV. DESCRIPTION OF TESTS

(U) A hydrophone of known receive response was used to calibrate the Artemis source and a projector of known transmit response was used to calibrate the receive system. A small landing craft (LCVP) was used as the surface platform to keep the calibration projector or hydrophone at the proper bearing and distance from the face of the array. A winch installed on the LCVP was used to lower the projector or hydrophone to the desired depth.

(U) The LCVP was kept at a constant distance and the proper bearing from the ship by keeping a cable taut between the two vessels. Commands were given over a walkie-talkie to the LCVP's coxswain as to engine speed and rudder angle. Position of the LCVP was determined from a pelorus mounted on the rail of the ship at a point above the face of the array.

(U) The amount of cable that was paid out from the winch in the LCVP was measured on an in-line cable counter and observed by the winch operator. The hydrophone used in the source calibration was weighted by a 150 pound weight to assure that it would not be affected by the ocean currents. The projector used was heavy enough not to require extra weights. The Artemis source was lowered to a depth

of 500 feet which is deep enough to eliminate surface reflections from interfering with the calibration. When the Artemis source is at 500 feet the calibration hydrophone and projector suspended from the LCVP had to be lowered only about 1,000 feet for a vertical profile of ±45°.

V. MEASUREMENTS

(U) Equations for determining the far field distance from the source were investigated for a frequency of 400 Hz or a wave length of 12 feet. R. J. Bobber[3] gives the criteria for response measurements for pistons where the diaphragm or act've area lies approximately in a plane normal to the acoustic axis. The equation for the far field distance X is as follows:

$$X \leq \frac{(\text{Maximum Dimension})^2}{\lambda}$$

Where X = distance to far field from source.

Maximum Dimension = 50 feet

λ = 12 feet for 400 Hz

λ = 9.6 feet for 500 Hz

$$= \frac{(50)^2}{9.6} = 260.4 \text{ feet for 500 Hz}$$

$$= \frac{(50)^2}{12} = 200 \text{ feet for 400 Hz}$$

(U) Bobber also states that beam pattern measurements require more separation than response measurements. The 300 foot separation used is a compromise distance for being in the far field yet being close enough to the ship for small boat maneuverability.

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(3) Bobber, R. J., "Underwater Electroacoustic Measurements", Government Printing Office, Library of Congress Catalog Card No. 72-608304, July 1970, pg. 127.

(U) As the output frequency is varied from the resonant frequency a mismatch is created between the power amplifier and the array. This mismatch results in a large output voltage which could damage either the array or the power amplifier if the drive to the amplifier is high enough. For this reason the load current for the source response measurements was limited from 1 to 10 amperes over the frequency range of 100 to 500 Hz. Near the resonant frequency the output current was increased to 100 amperes to complete the source response measurements. Forty millisecond pulse lengths were used in all measurements.

(U) The separation distance between the Artemis source and the hydrophone suspended from the small boat was determined by the measurement of the travel time of sound between the source and the receive hydrophone. This measurement was made to an accuracy of ±1 millisecond or ±5 feet. The calculation which converted the time measurements into distance was computed using an average sound speed of 5,000 feet/second. The main contributor of propagation loss at the frequencies of interest is inverse spreading. Since slant range was determined to a ±5 foot accuracy the error in computation of propagation loss is much less than 1 db.

(U) The calibration of the Artemis source and receiving array was determined by the comparison method. By this method the calibrated transducer is placed on the axis of the source being calibrated at a known separation and its output measured. Since the Artemis source is tilted upward 11° the known transducer must be placed at different depths as the measuring azimuth is changed to stay in a plane through the axis. The depth of any point on this plane is a function of the azimuth angle and the separation from the source, i.e., when the Artemis source is at a depth of

500 feet with a separation of 300 feet, the depth of the main axis at 0° azimuth (in front) is 443 feet at that point. When the separation and source depth are as previously described but the azimuth angle is 180° (back side) the main axis is at 557 feet. Therefore, the depth varies from 443 feet to 557 feet as measurements are made from 0° to 180° around the source.

(U) Cable loss for the suspended hydrophone used in the receive measurements was calculated by the following formula:

$$\text{Cable loss (db)} = -20 \log \frac{C_{hydrophone} + C_{cable}}{C_{hydrophone}}$$

Calibration of the hydrophone suspended from the LCVP was made with the cable used with the source calibration.

VI. RESULTS

(C) The measurements of sound level for the Artemis source from 1 to 100 amps are shown in a curve in Figure 3. Figure 4 shows good linearity of the system at 400 Hz. Here the source level increases from 99 to 145 db as the current is increased from 1 to 100 amps.

(C) The table below shows the source level measurements at several frequencies taken at 20 amps; included are Ferris and Rollins[1] source level measurements.

Frequency Hz	Flato SL	Ferris & Rollins SL	Difference
300	120 db re μbar @ 1 yd	117 db re μbar @ 1 yd	+3
350	125	122	+3
400	129	128	+1
450	132	130	+2
500	128	127	+1

This table shows that the source level of the recent measurements is greater than previously reported.

(U) It is possible that the earlier high frequency (500 Hz) measurement made at 190 feet distance is about 0.6 db too low due to diffraction according to equations by A. Freedman.[4] The corresponding diffraction error for the present measurements at 500 Hz would be only about 0.3 db lower. At lower frequencies this diffraction error becomes negligible for both sets of measurements and cannot explain the difference between results. Thus no explanation is given for the higher source level reported herein over that reported by Ferris and Rollins[1] except that modifications were made on the source from time to time during the period between measurements.

(U) Fourteen vertical beam patterns, Figures 5 through 18, were obtained at 400 Hz from forward around the left to the back side of the source. Most of the vertical beam patterns were acquired from 45° above to 45° below the on-axis bearings. The geometric and acoustic axes did not coincide, i.e., the maximum lobe did not lie on the geometric axis. It appears that the beam could have been tilted up as much as 5°. Since the resolution of the vertical measurements was 5° in the vicinity of the main axis the exuct difference between the geometric and acoustic axes is in doubt. Acoustic refraction and water current were investigated as a probable cause of the axes differences. These proved to cause a negligible change in the acoustic or geometric axis. Although no explanation could be derived for the difference in the measured main lobe and the geometric axis of the vertical beam patterns, each was adjusted to have the main lobe located on the geometric axis.

[4] Freedman, A. "Sound Field of a Rectangular Piston, Journal of the Acoustical Society of America, Vol. 32, No. 2, February 1960.

(C) The azimuthal main beam pattern is shown in Figure 19. It was derived from the corrected 0° readings of the fourteen vertical beam patterns. It can be seen from the horizontal beam pattern that the main beam width is 40° at the 10 db down points. The back beam is 16 db lower than the front beam. The vertical beam is 24° wide at the 10 db down points.

(U) The response curves for the face and extended receiving arrays on the Artemis source are shown in Figure 20. Also included in Figure 20 are the single hydrophone on the face, the single hydrophone on an extended arm, and a hydrophone suspended 300 feet below the array. Identical hydrophones[2] having a sensitivity of -89 db re 1 volt per μbar were used for the suspended hydrophone, single hydrophones at the face, and in the planar arrays.

(C) The following table shows the array gains for each of the planes of the hydrophones compared to the single hydrophone suspended below the array:

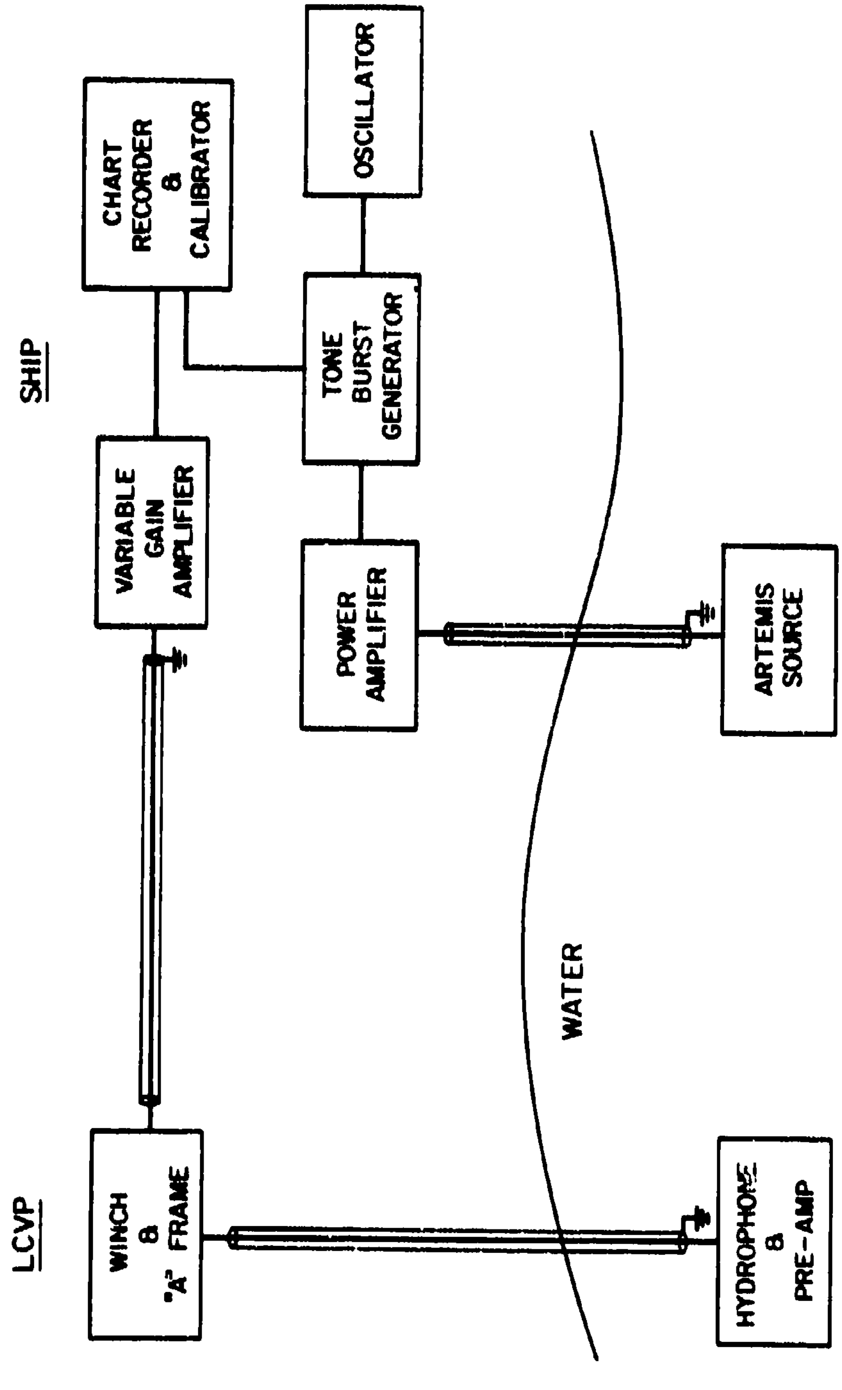
	277.5 Hz	380 Hz	400 Hz	500 Hz	750 Hz	Ave.
Extended Single Hydrophone Compared to Suspended Hydrophone	2	19	12	12	5	10
Face Single Hydrophone Compared to Suspended Hydrophone	9	14	11	9	2	9
Extended Single Hydrophone Compared to Face Single Hydrophone	-7	5	1	3	3	1
Array Gain Extended Array	15	14	19	18	14	16
Array Gain Face Array	3	9	9	6	10	7.4
Extended Planar Array Compared to Face Planar Array	12	5	10	12	4	8.6

(U) It can be seen from Figure 20 and the Table above that a single hydrophone attached directly on the face of the planar array and the single hydrophone on the extended planar array have higher receive sensitivities than the single free hydrophone suspended 300 feet below the source. This shows that the compliant squash tubes acting as reflectors provide gain to the single hydrophones in close proximity to them. The receive sensitivity of the extended single hydrophone is higher than the face single hydrophone by an average of 1 db across the band of frequencies measured. The inconsistency in the receive sensitivity between the face and extended single hydrophones in the band of interest could possibly be due to interference (both constructive and destructive) in the arrival of signals from the calibrated source and that reflected from the compliant squash tubes.

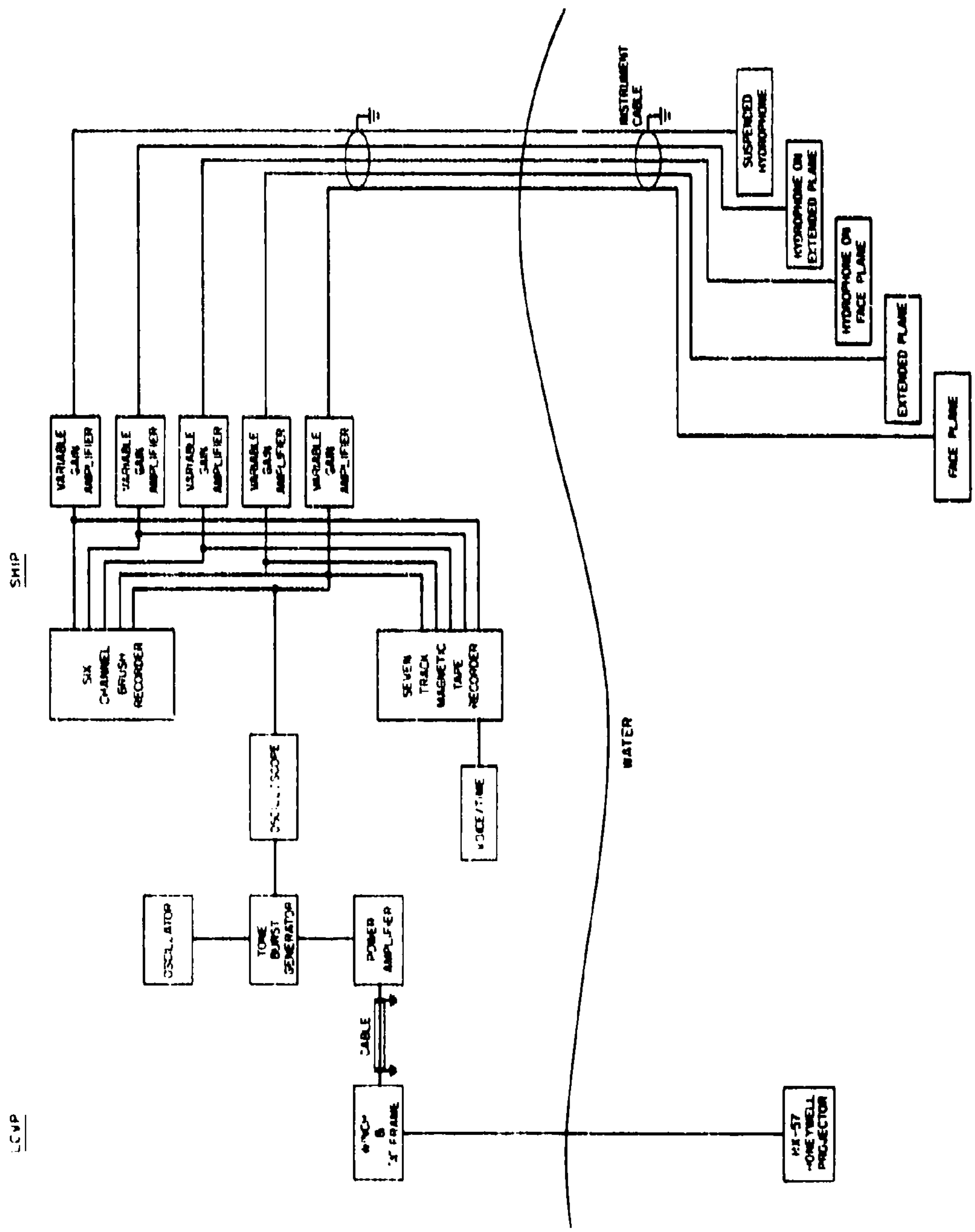
(C) Array gain for each planar array was derived by determining the difference between the receive sensitivity of the planar hydrophones and the sensitivity of the single hydrophone in that plane. The theoretical maximum array gain for a plane of 42 hydrophones is 10 log 42, or 16.2 db, i.e., for a perfectly coherent signal in incoherent noise.[5] This calculation for array gain is for the array of hydrophones only and does not include the influence of the reflector behind the source. Theoretically, the reflector can add as much as 6 db to the receive sensitivity of the array. The combined maximum theoretical gain for the planar array therefore is 22.2 db.

(U) The extended array has the higher array gain of the two planar arrays, but is 6 db below the theoretical maximum. The planar array on the face has a much lower array gain than the extended array which can be explained in part by its close proximity to the reflector.

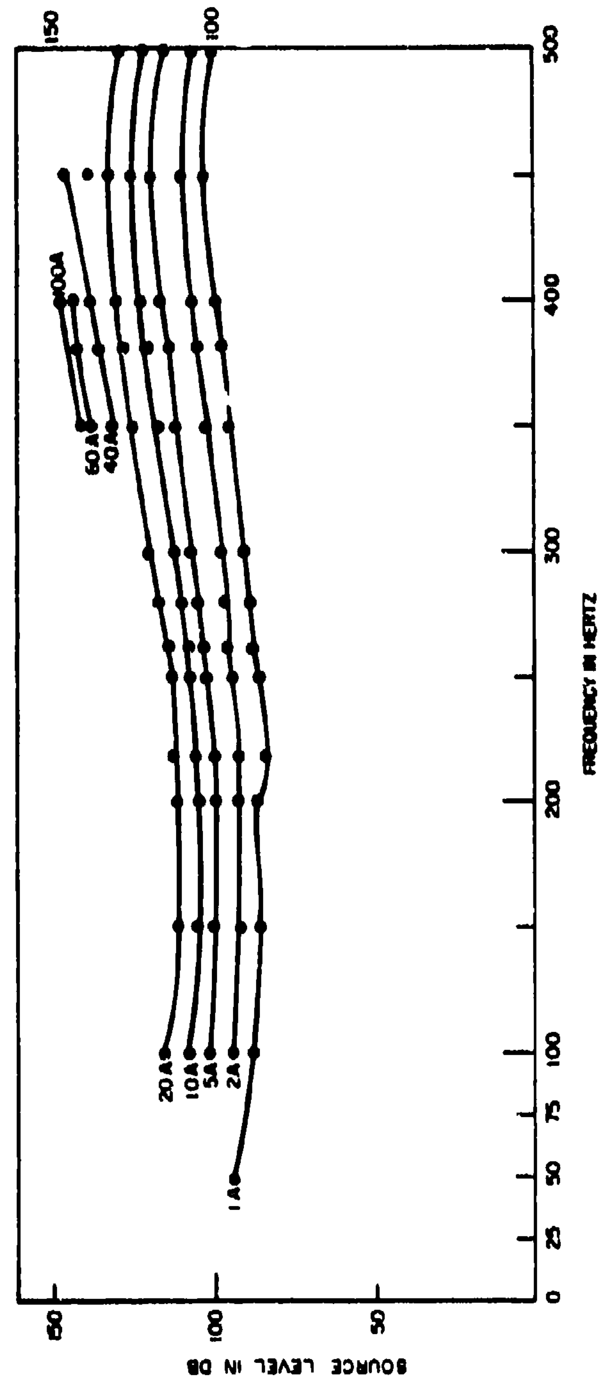
[5] Urick, R. J., "Principles of Underwater Sound for Engineers", McGraw-Hill, 1967, pg. 49.



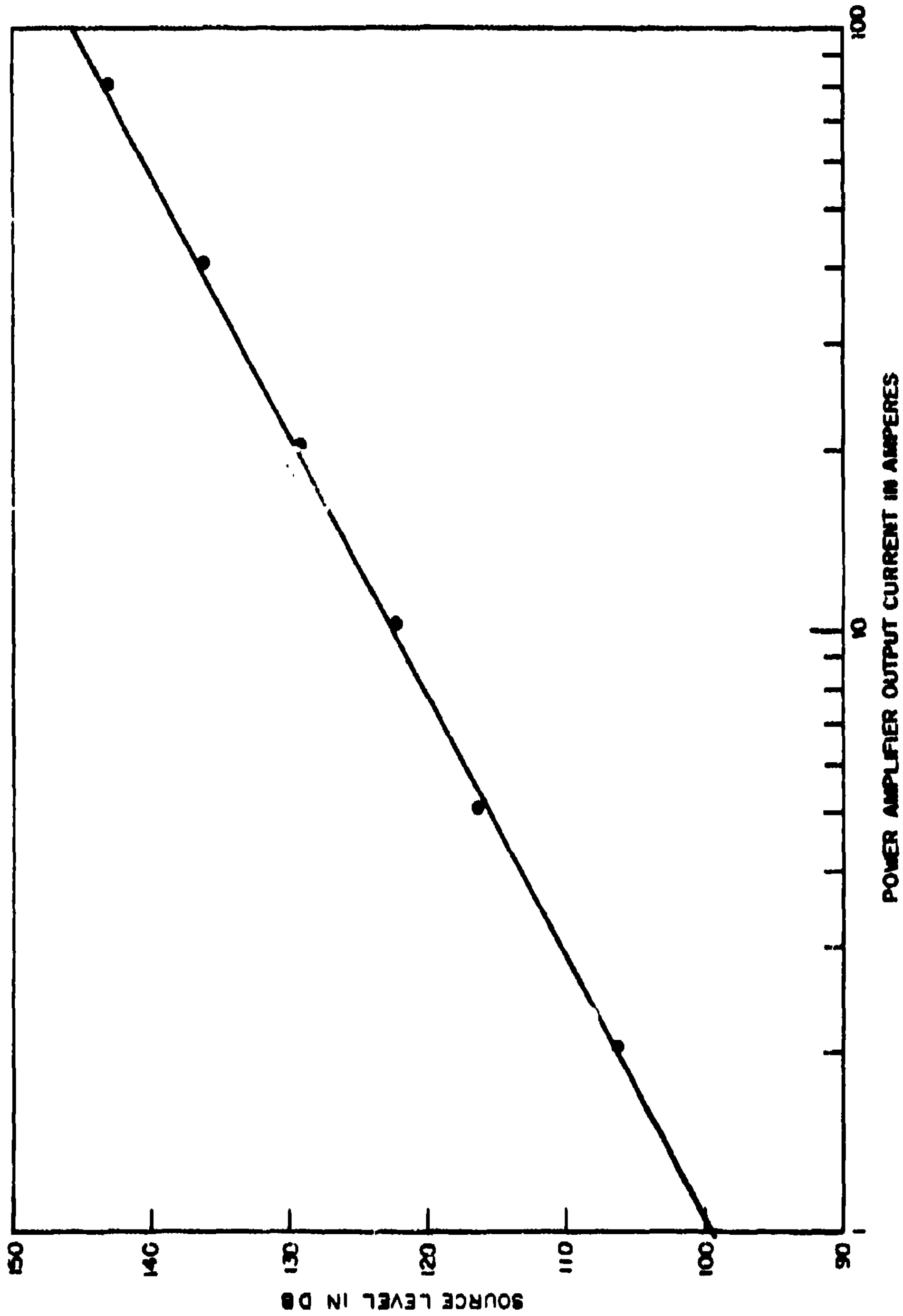
(U) Fig. 1 - Transmit calibration block diagram



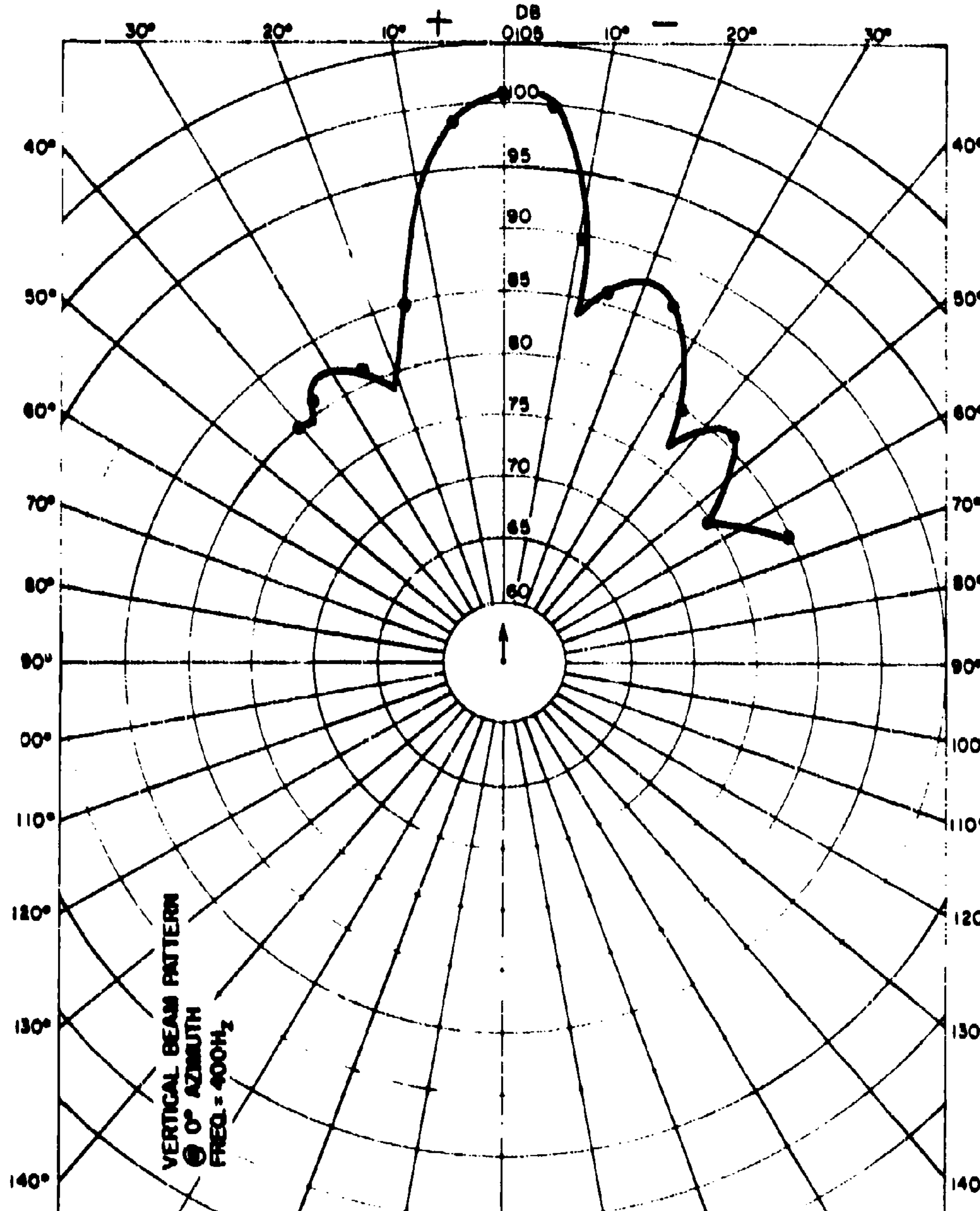
(U) Fig. 2 - Receive calibration block diagram



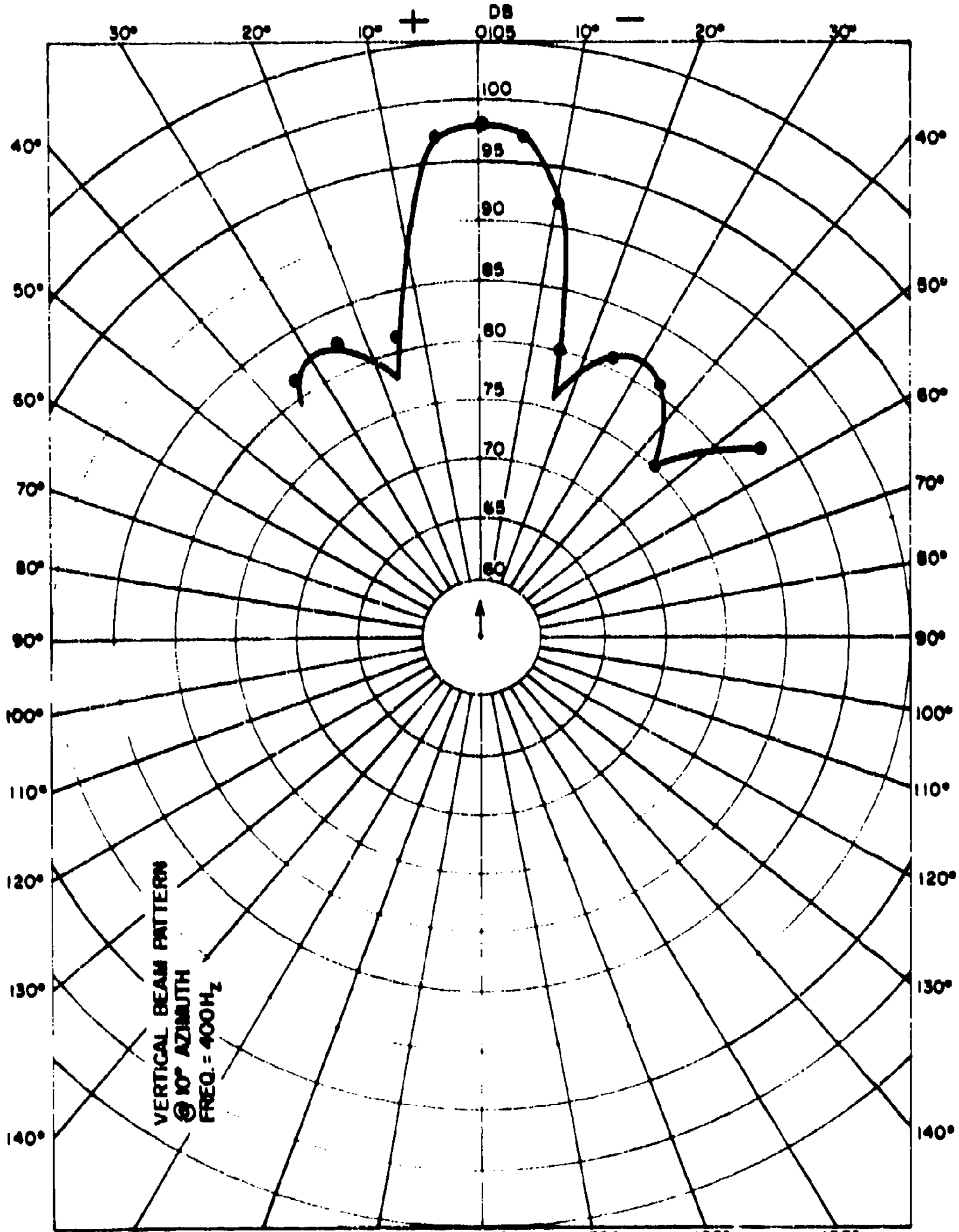
(C) Fig. 3 - Source transmit response



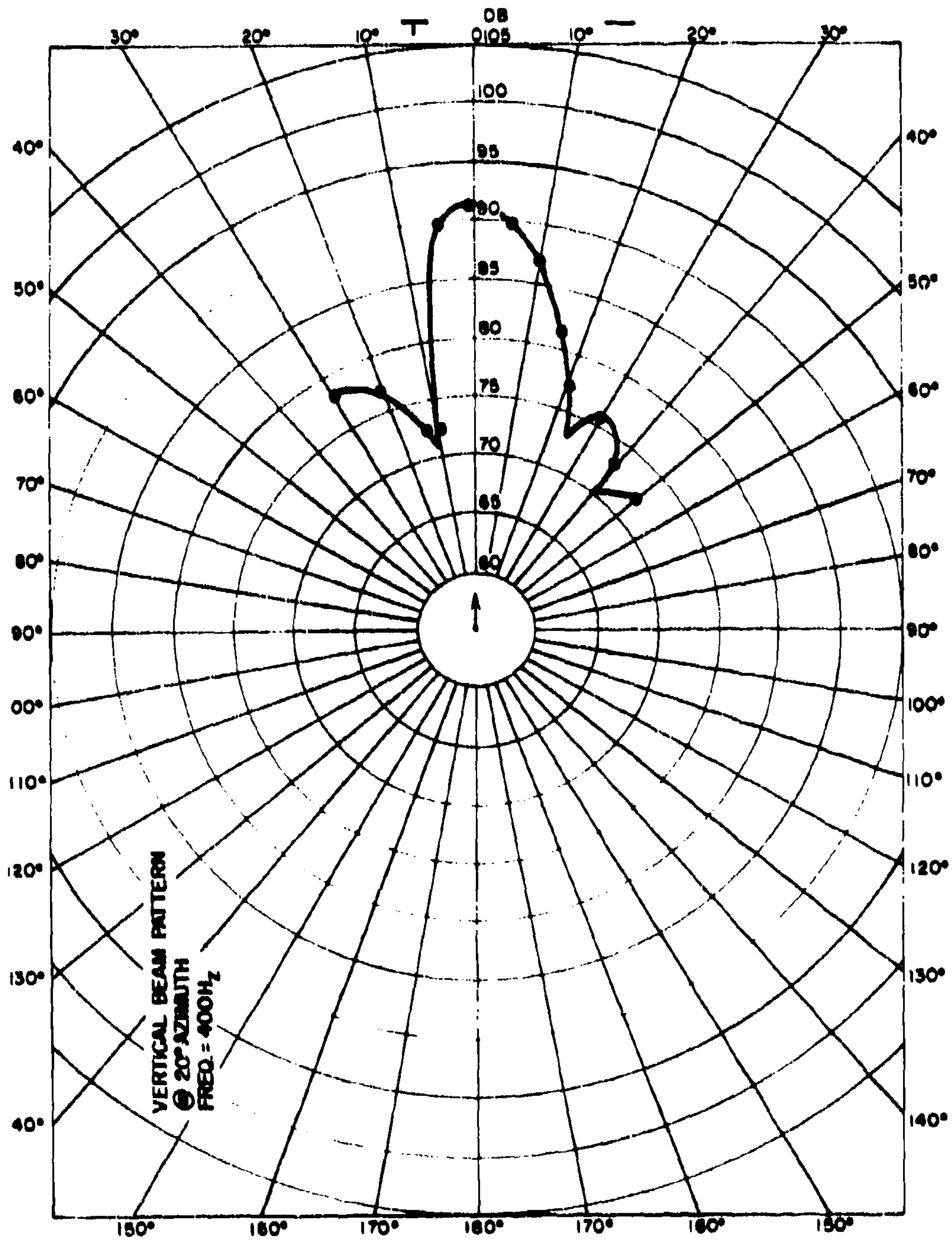
(C) Fig. 4 - Power output linearity



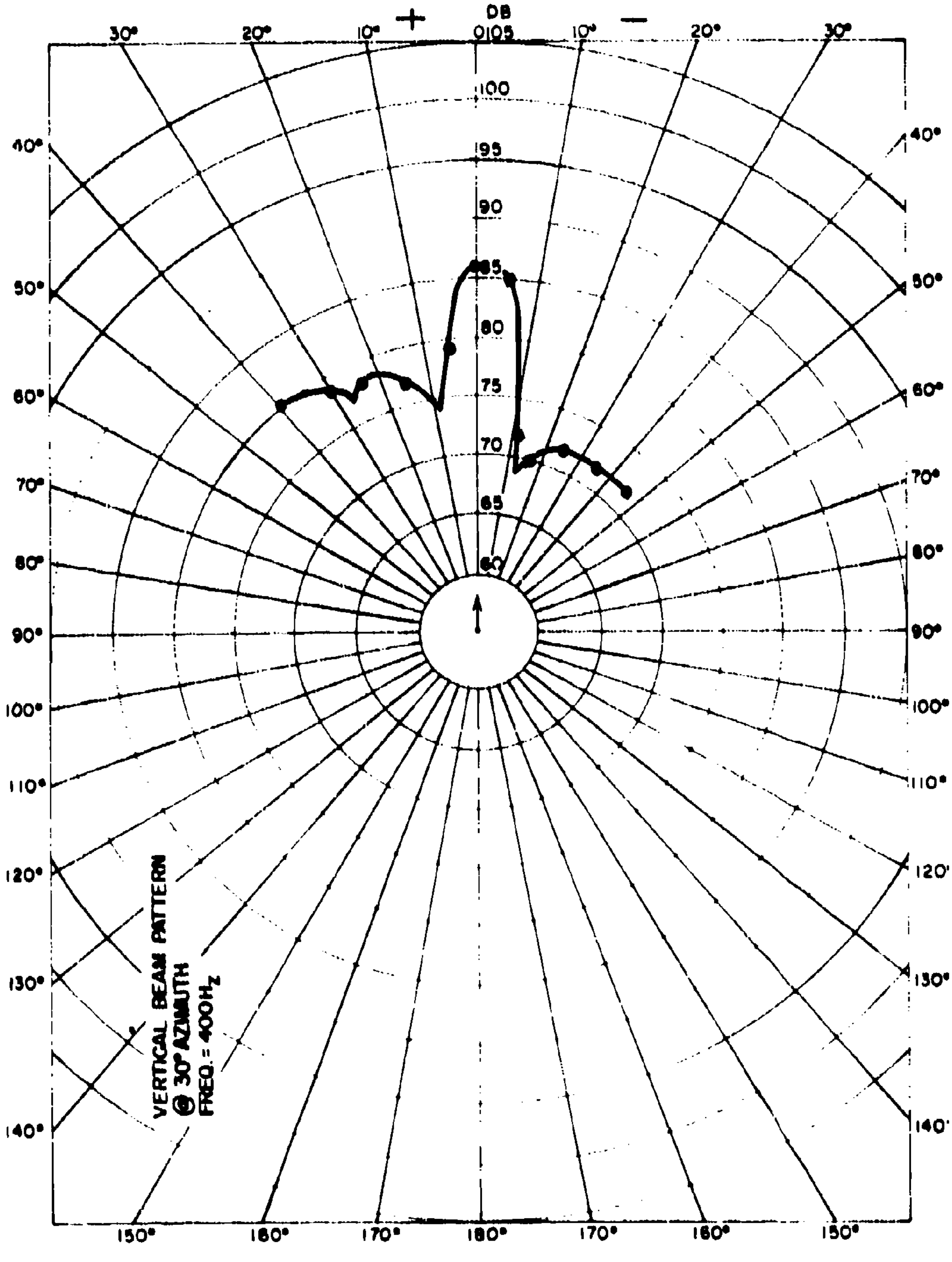
(C) Fig. 5 - Vertical beam pattern @ 0° azimuth



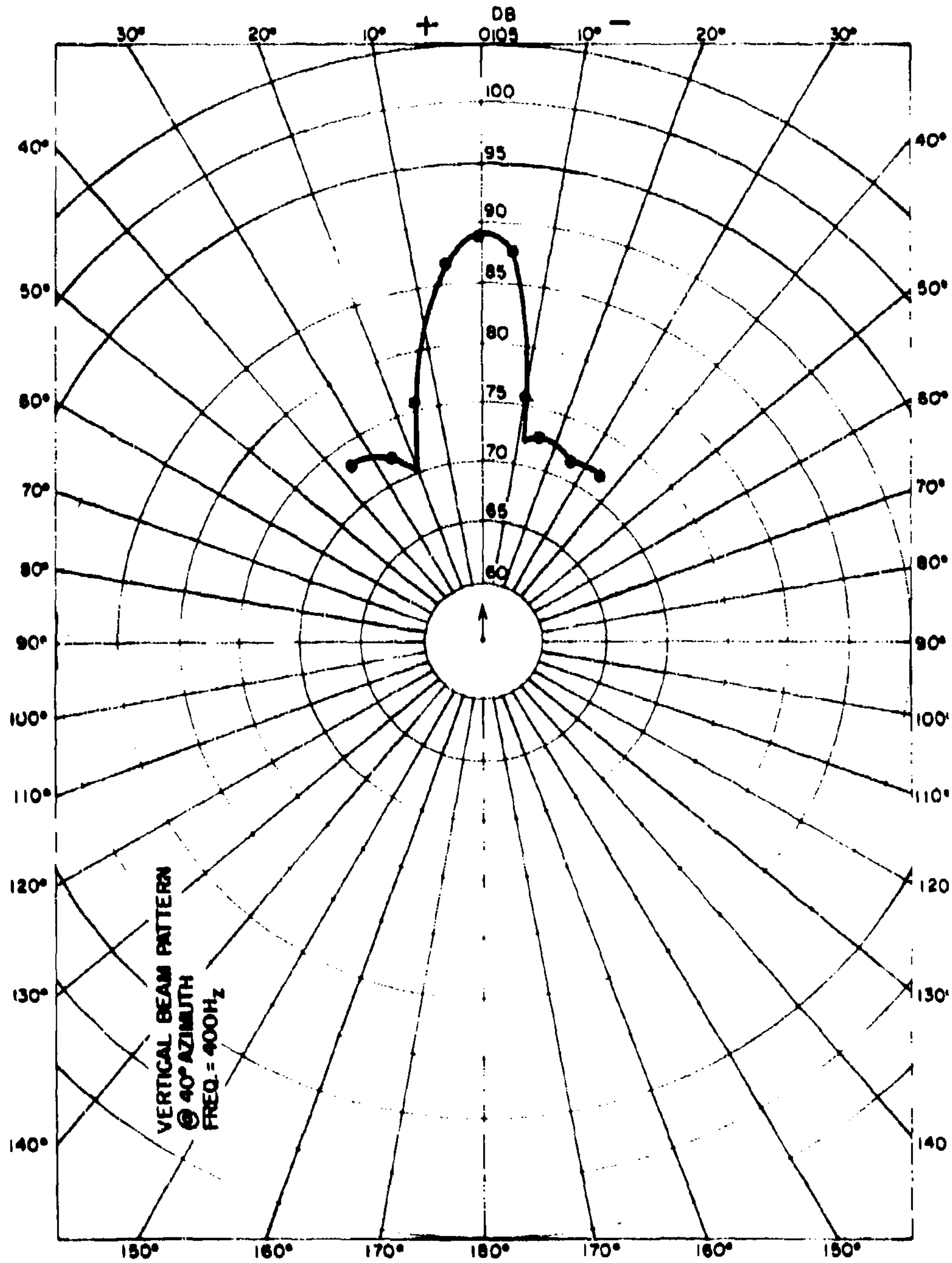
(C) Fig. 6 – Vertical Beam pattern @ 10° Azimuth



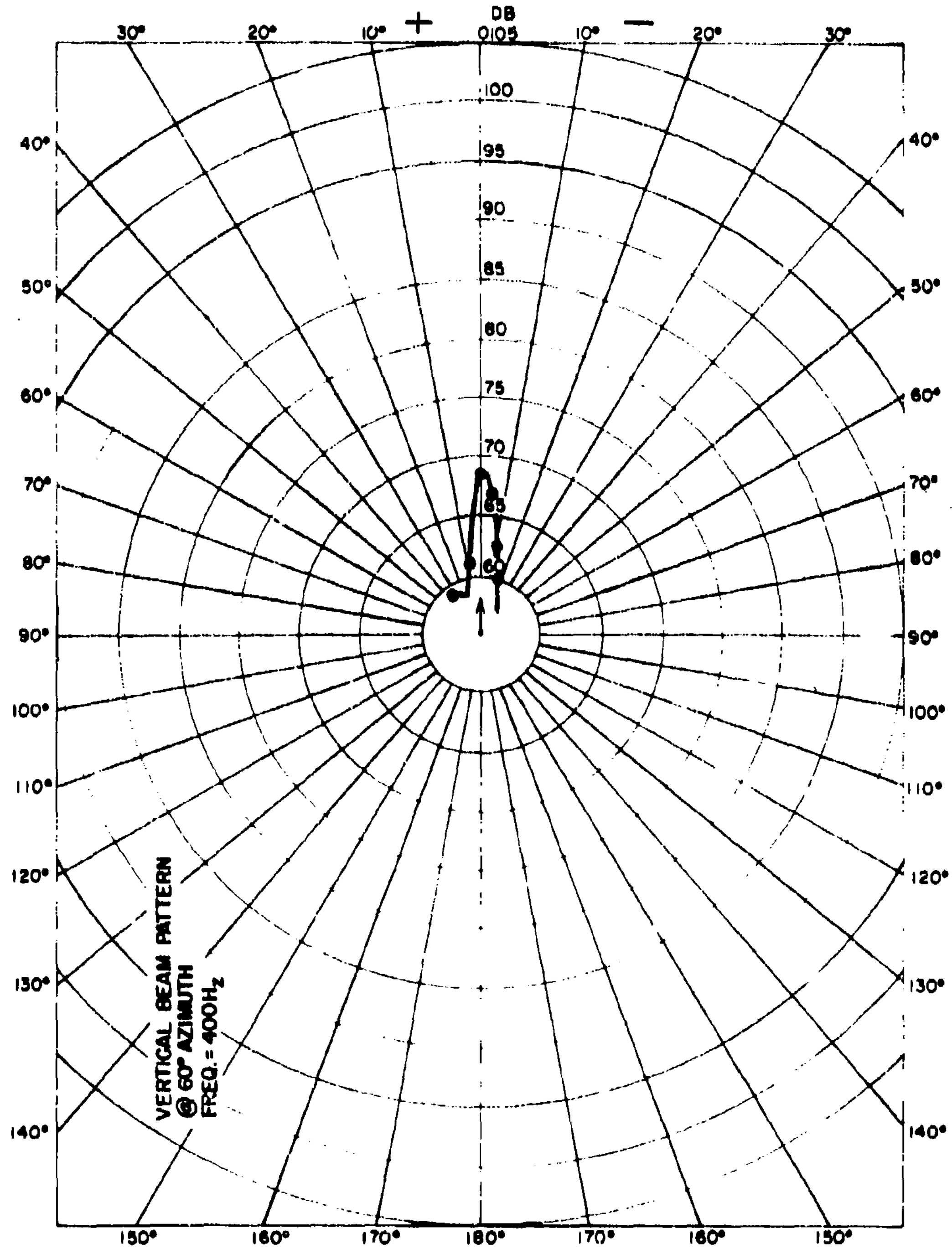
(C) Fig. 7 - Vertical beam pattern @ 20° Azimuth



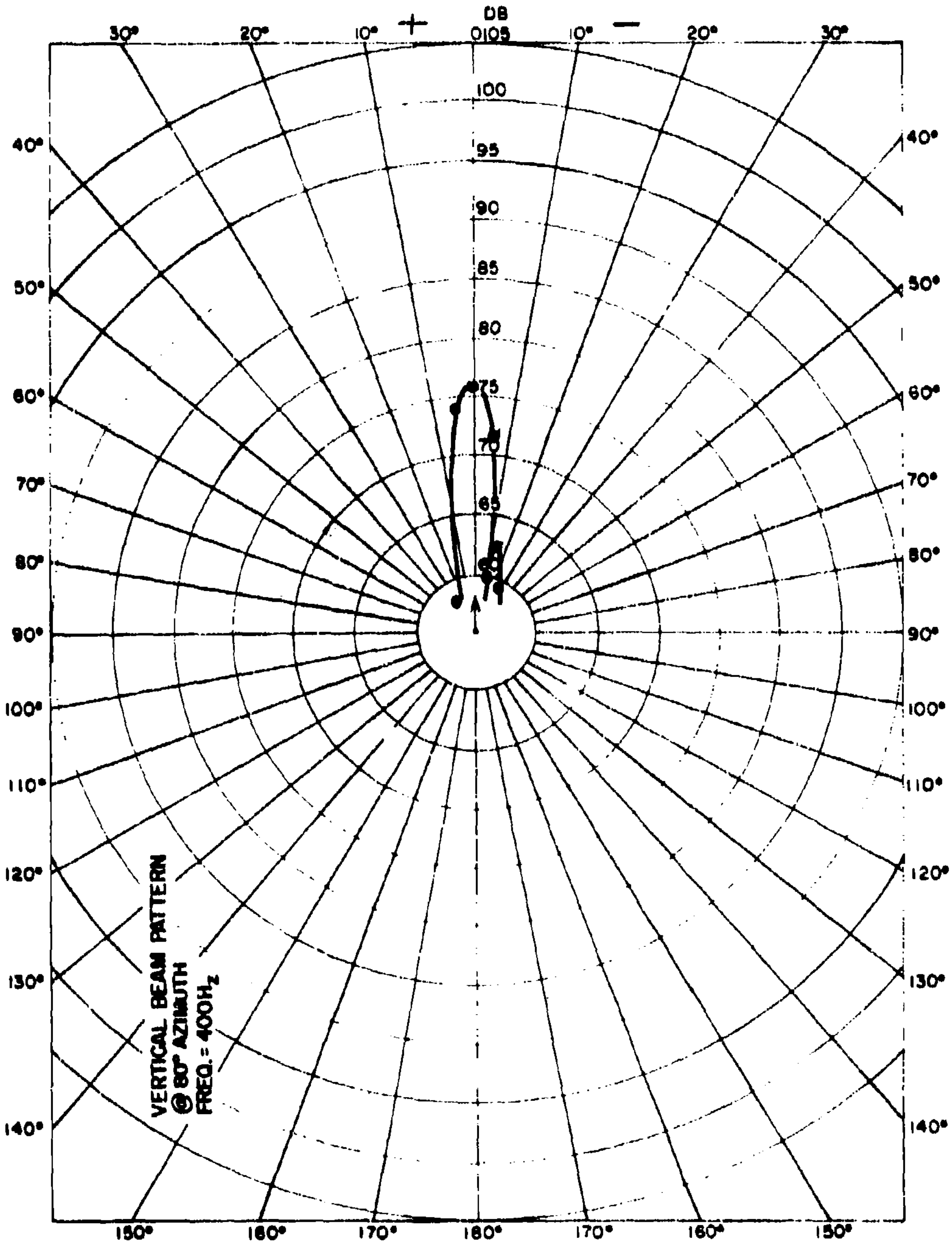
(C) Fig. 8 - Vertical beam pattern @ 30° Azimuth



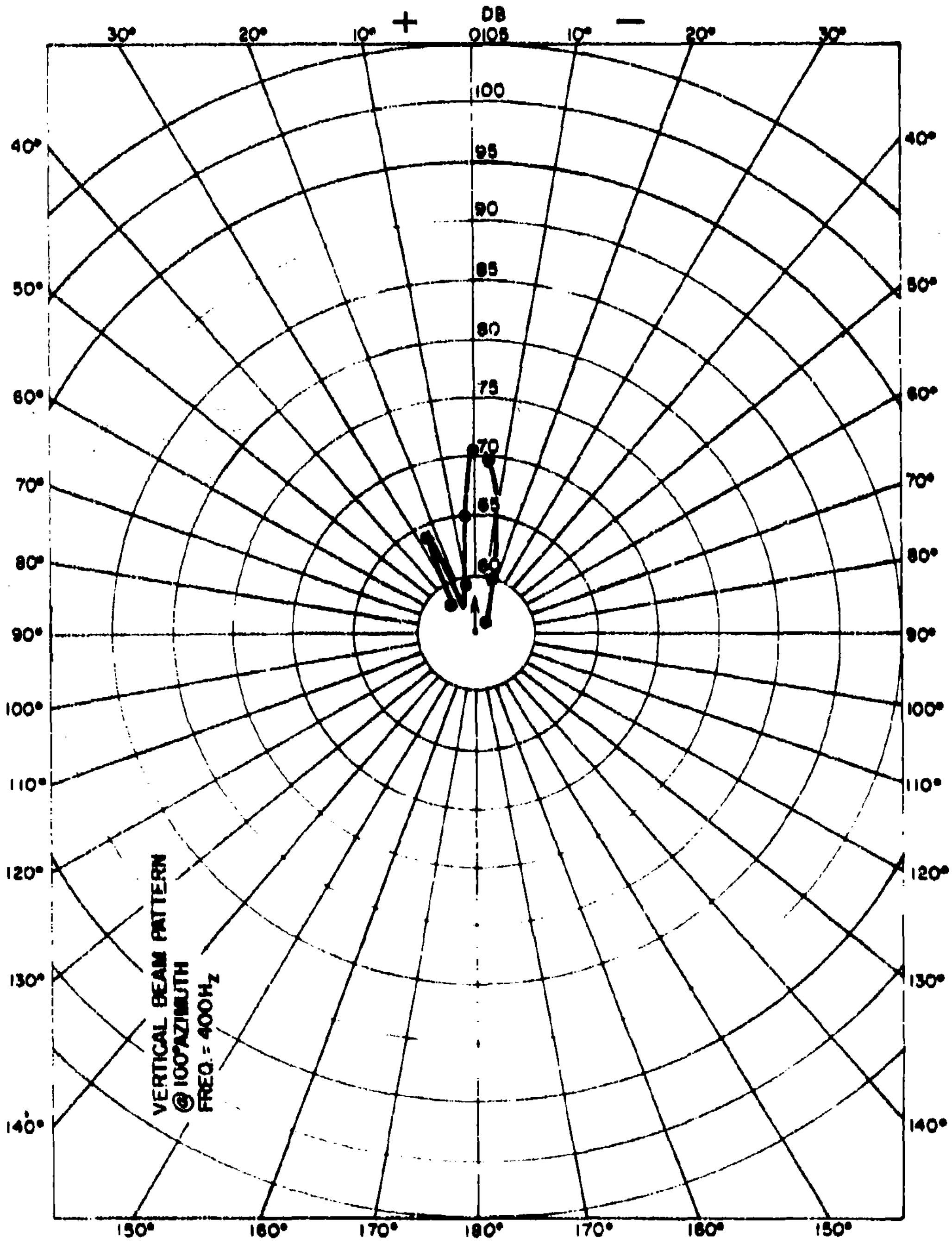
(C) Fig. 9 – Vertical beam pattern @ 40° Azimuth



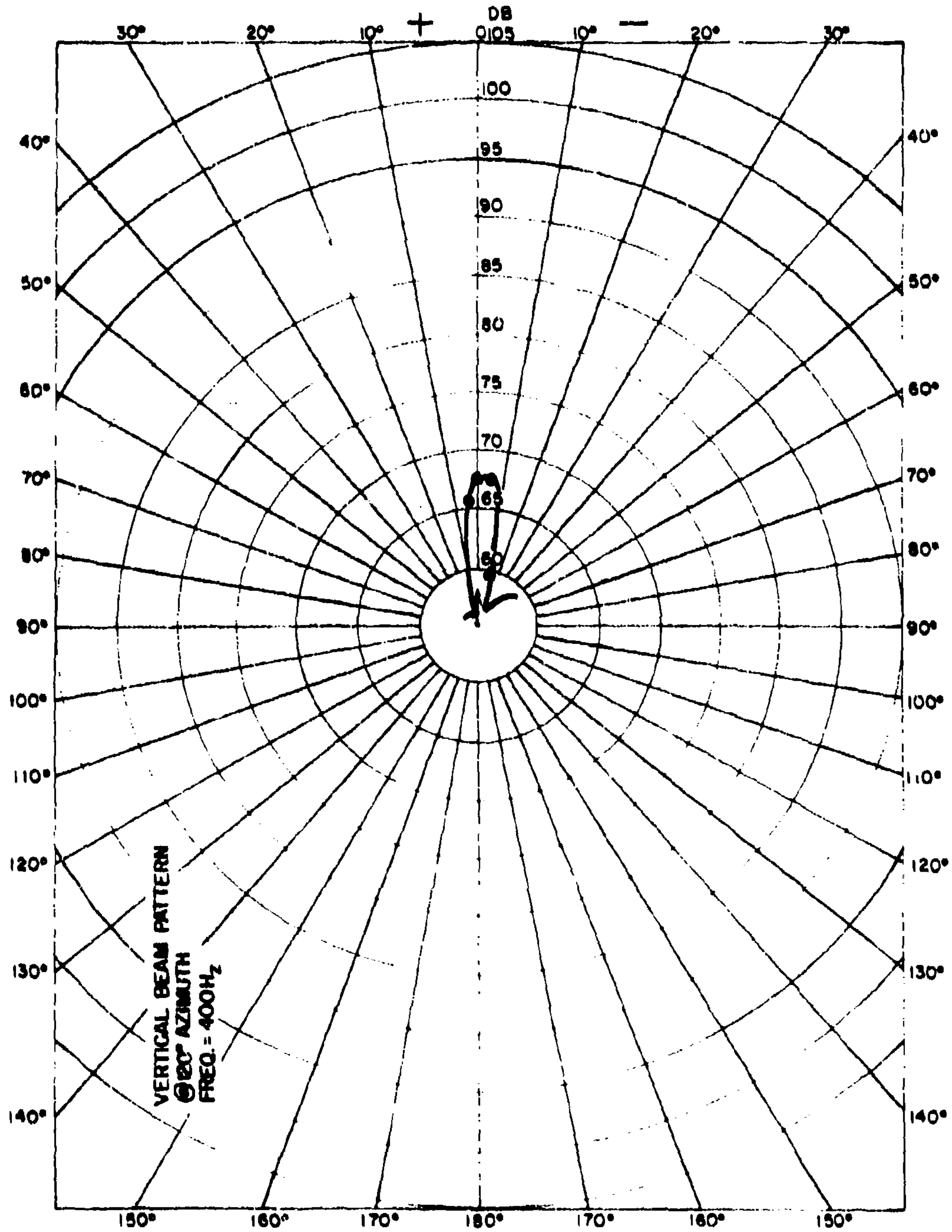
(C) Fig. 10 - Vertical beam pattern @ 60° Azimuth



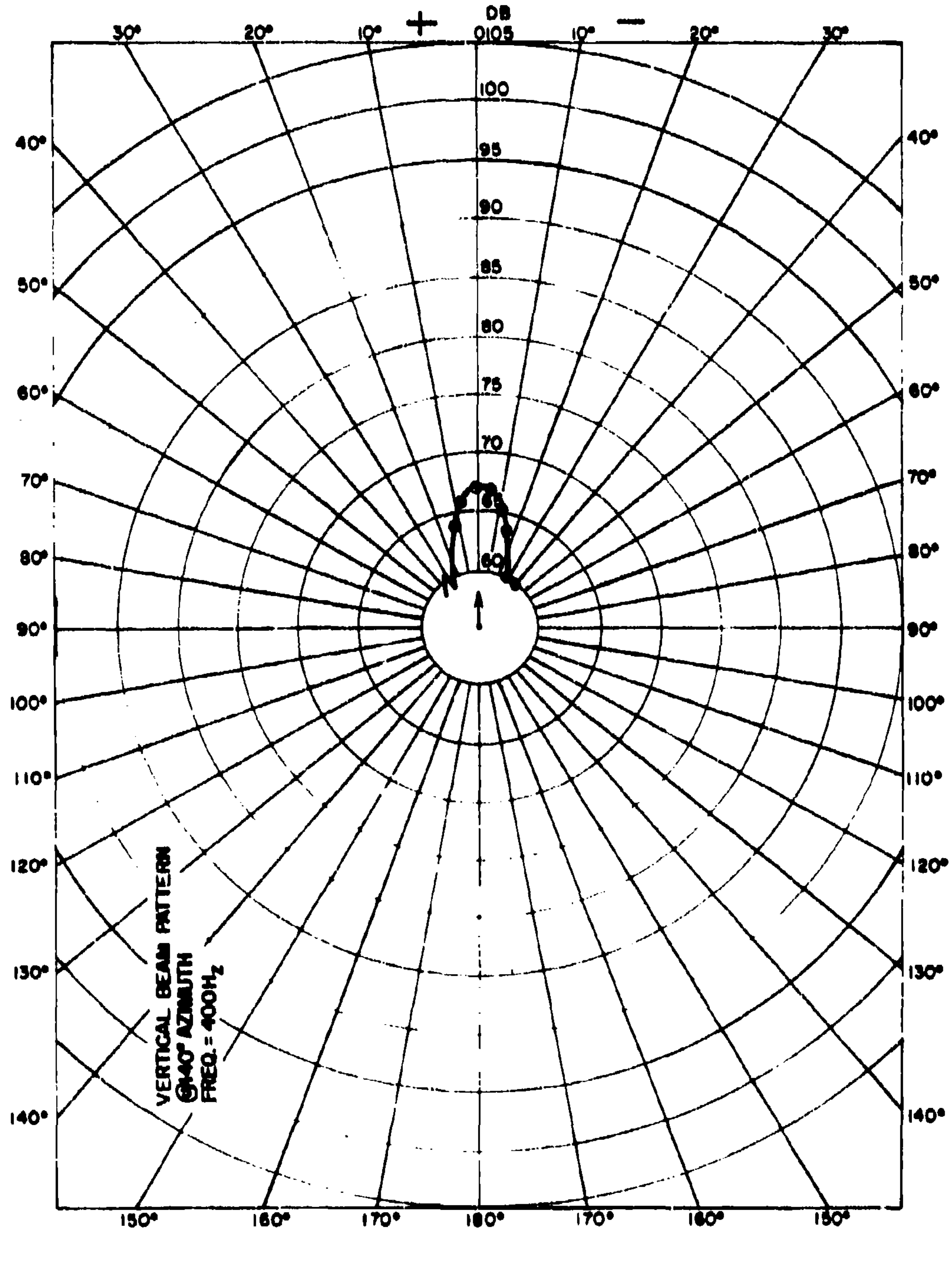
(C) Fig. 11 - Vertical beam pattern @ 80° Azimuth



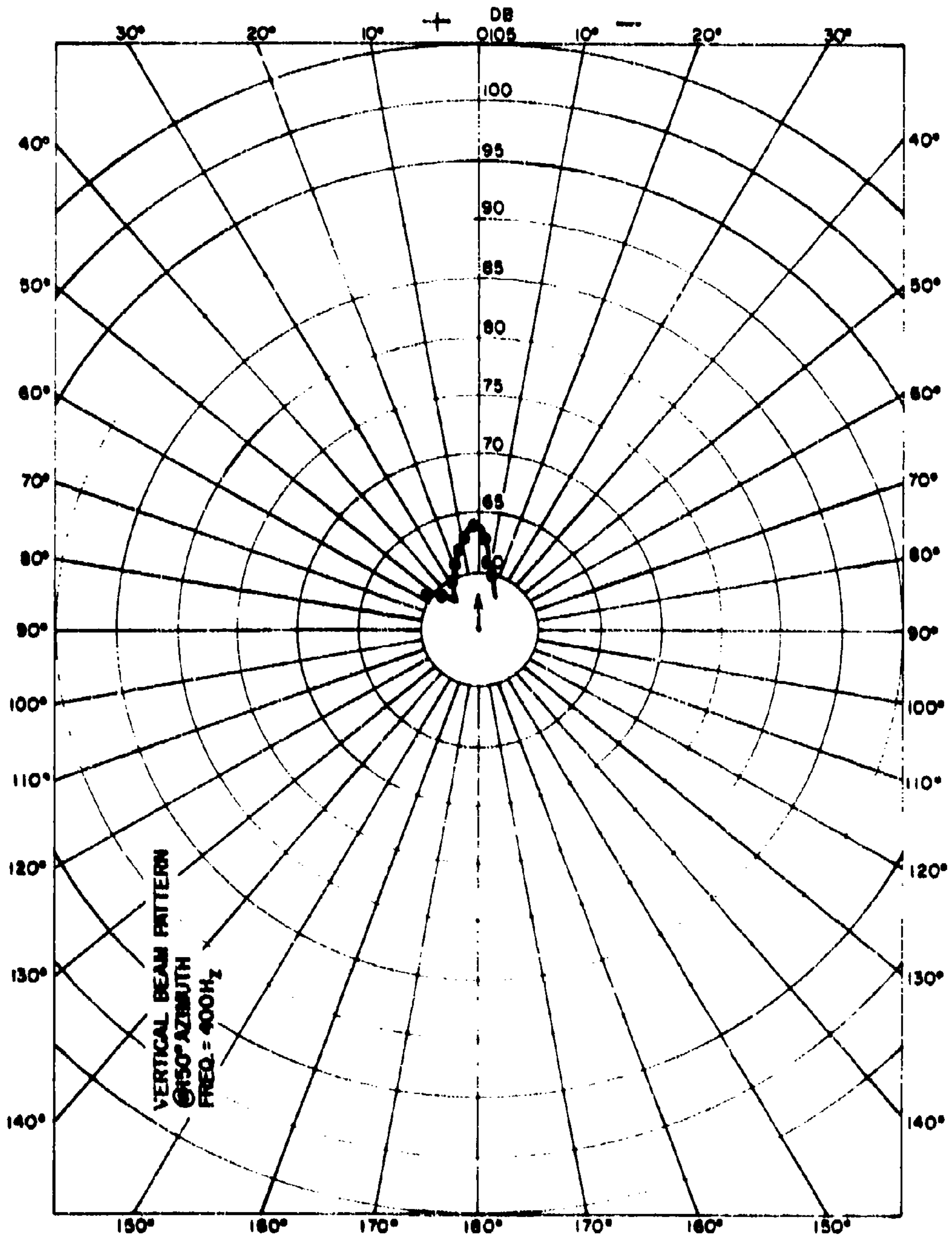
(C) Fig. 12 - Vertical beam pattern @ 100° Azimuth



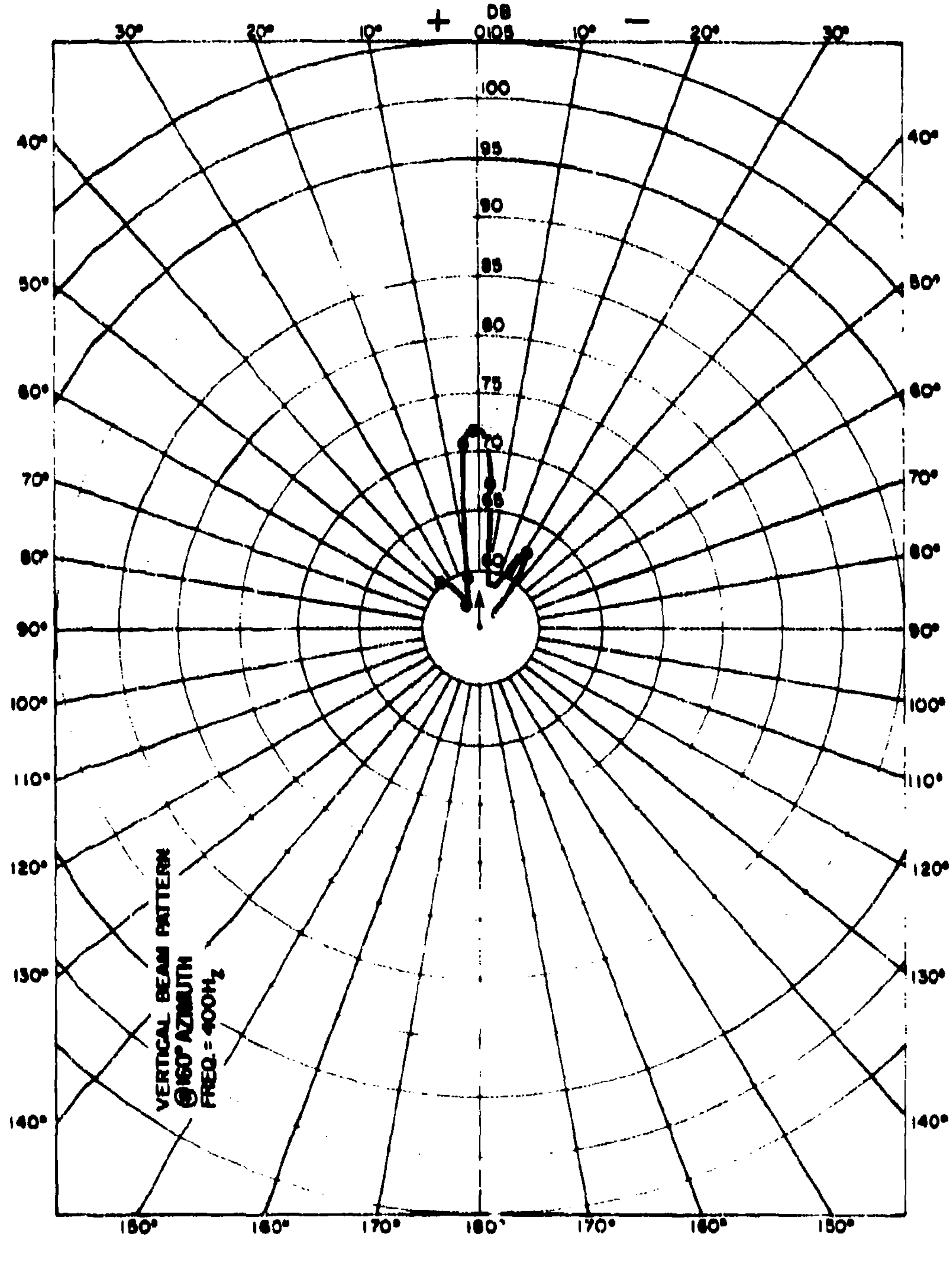
(C) Fig. 13 - Vertical beam pattern @ 120° Azimuth



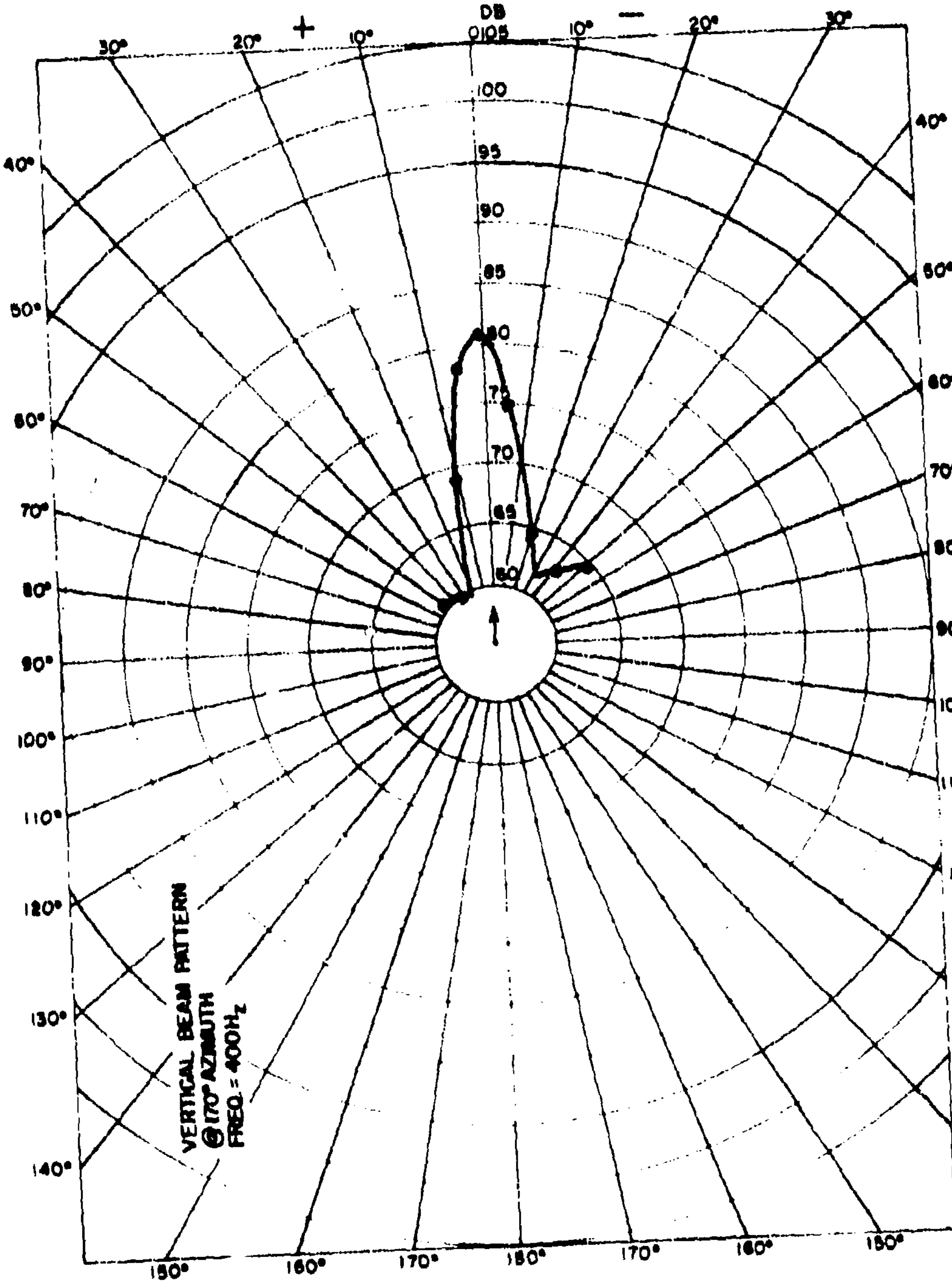
(C) Fig. 14 - Vertical beam pattern @ 140° Azimuth



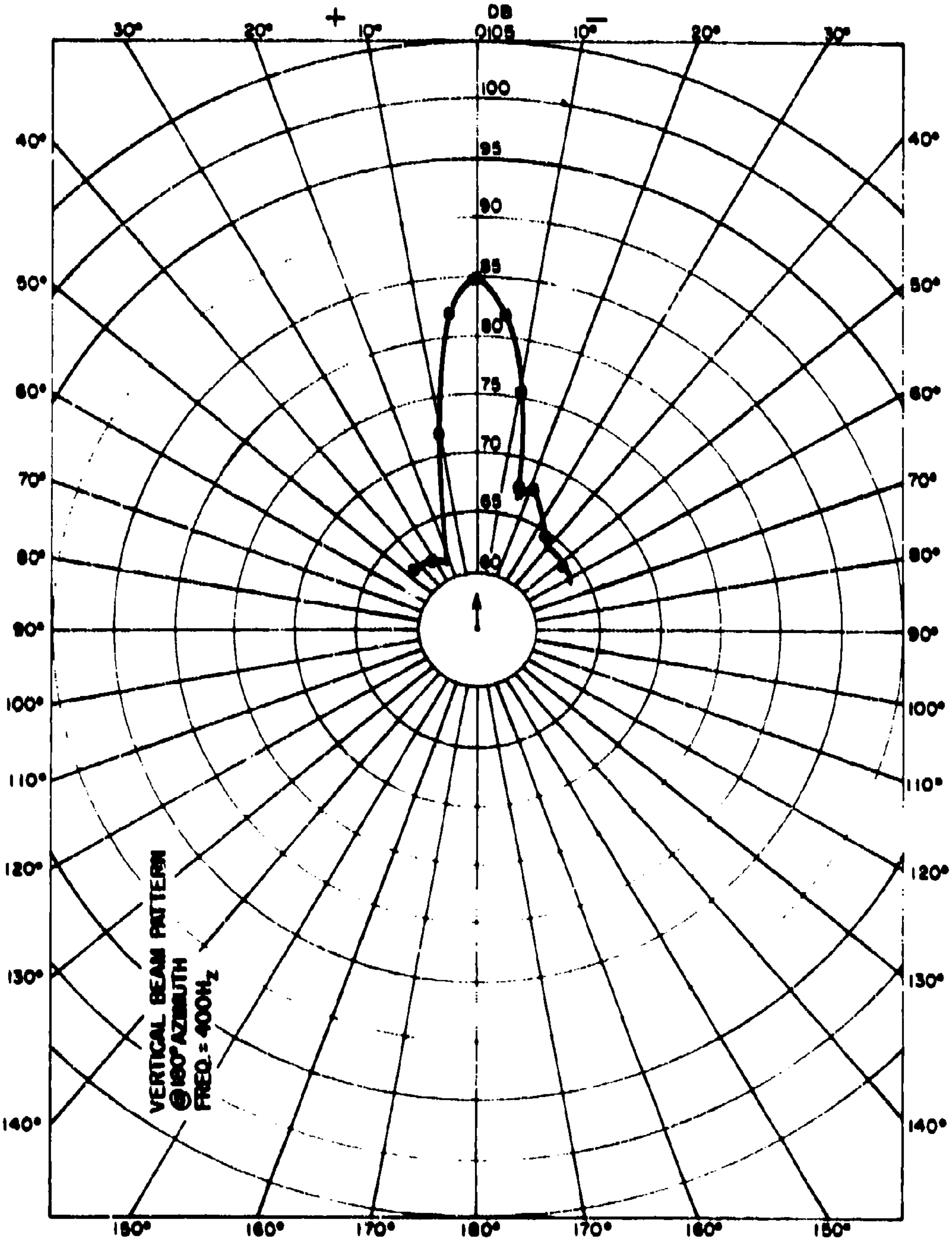
(C) Fig. 15 - Vertical beam pattern @ 150° Azimuth



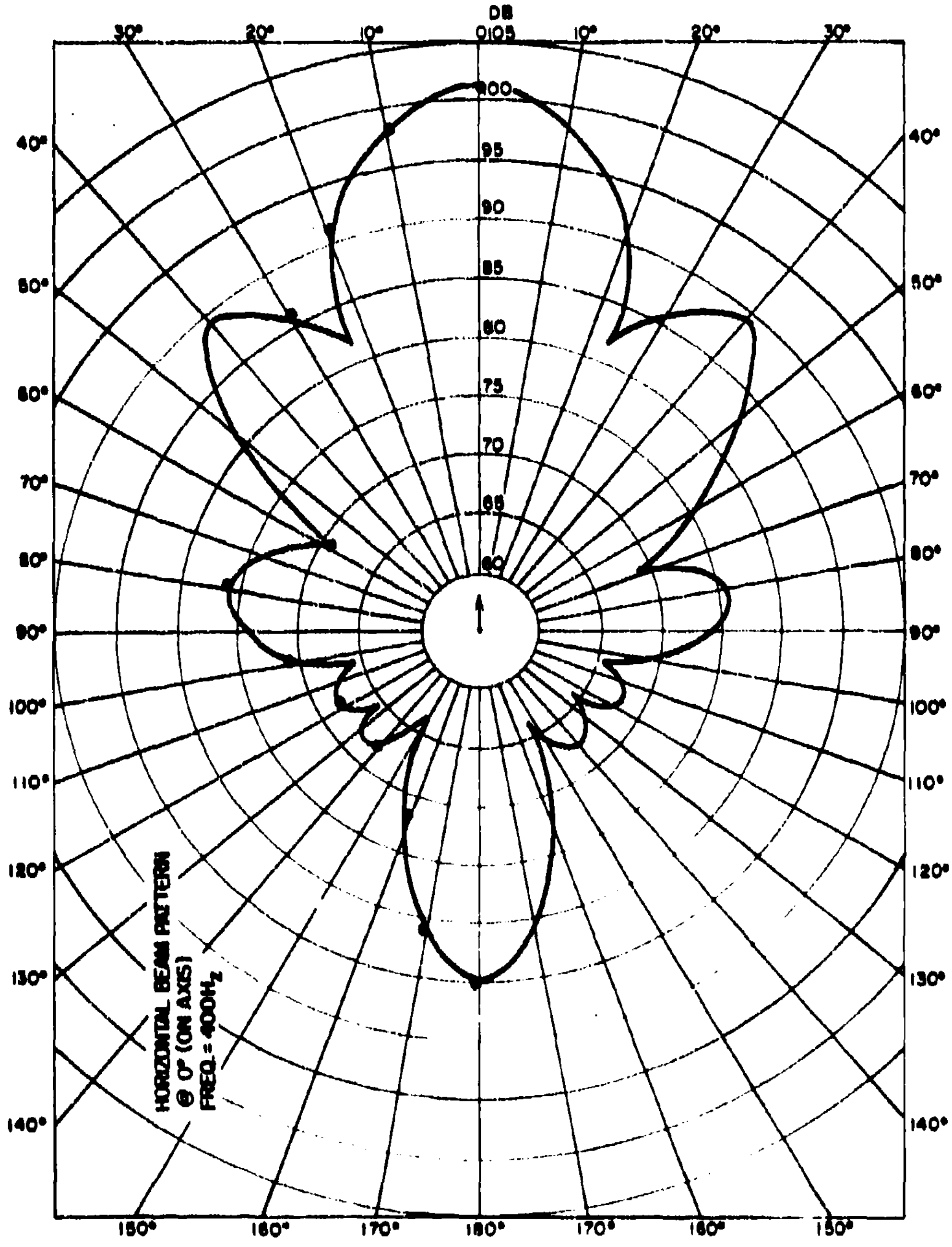
(C) Fig. 16 - Vertical beam pattern @ 160° Azimuth



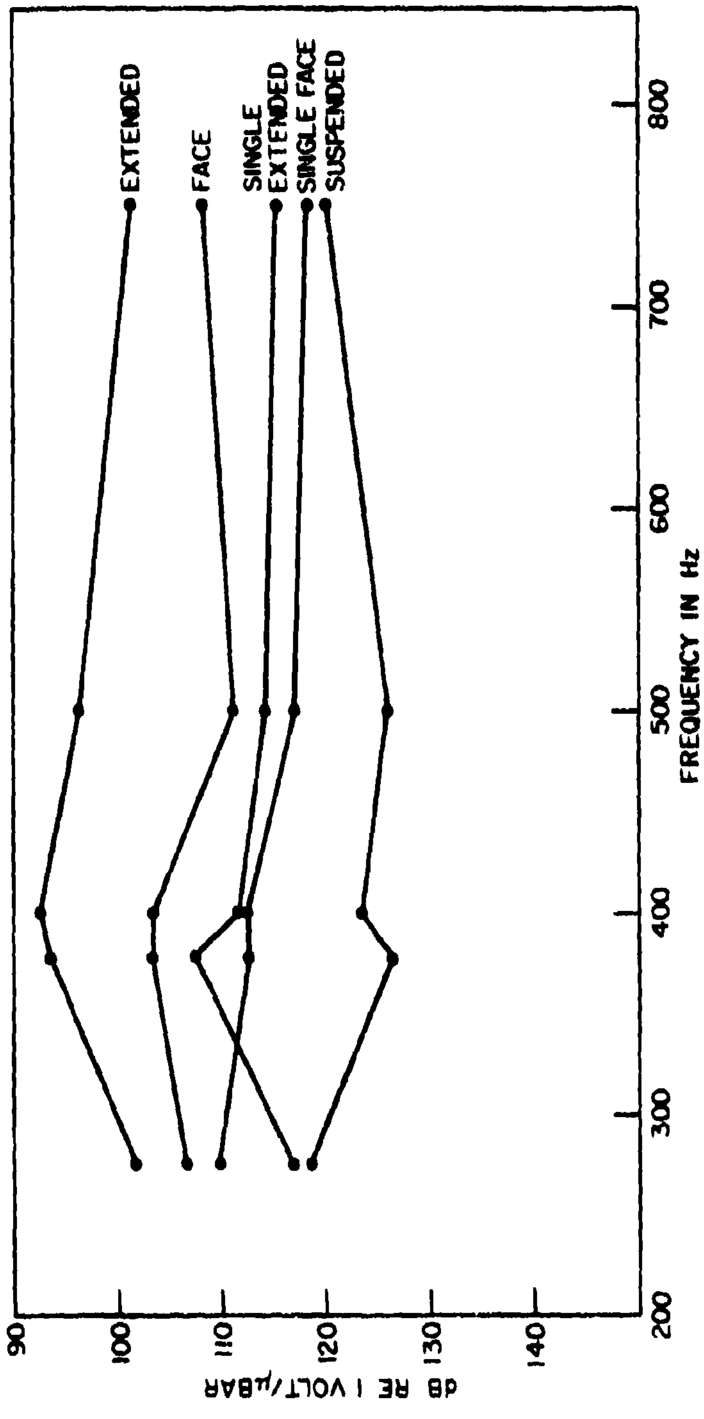
(C) Fig. 17 - Vertical beam pattern @ 170° Azimuth



(C) Fig. 18 - Vertical beam pattern @ 180° Azimuth



(C) Fig. 19 - Horizontal beam pattern (On-Axis)



(C) Fig. 20 - Receive sensitivity response

UNITED STATES GOVERNMENT
Memorandum

7100-016

DATE: 22 January 2004

REPLY TO ATTN OF: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF (A) FOR DECLASSIFICATION

TO: Code 1221.1

REF: (a) "Project ARTEMIS High Power Acoustic Source", A.T. McClinton, R.H. Ferris, W.A. Herrington, Sound Div., NRL Memo Report 1205, 3 Aug 1961 (U)
(b) "Project ARTEMIS High Power Acoustic Source Second Interim Report on Acoustic Performance", A.T. McClinton and R.H. Ferris, Sound Division, NRL Memo Report 1214, 19 September 1961 (U)
(c) "Project ARTEMIS High Power Acoustic Source Third Interim Report on Acoustic Performance", A.T. McClinton, R.H. Ferris, Sound Division, NRL Memo Report 1273, 23 April 1962 (U)
(d) "Project ARETMIS High Power Acoustic Source Effect of Transducer Element Electrical Connection on Interaction in a Consolidated Array", A.T. McClinton, Sound Division, NRL Memo Report 1323, 4 June 1962 (U)
(e) "Test of Project ARTEMIS Source", R.H. Ferris, Sound Division, NRL Memo Report 1648, 15 September 1965 (U)
(f) "Power Limitations and Fidelity of Acoustic Sources", R.H. Ferris and F.L. Hunsicker, Sound Division, NRL Memo Report 1730, November 1966 (U)
(g) "Project ARTEMIS Acoustic Source Acoustic Test Procedure", R.H. Ferris and C.R. Rollins, Sound Division, NRL Memo Report 1769, 5 June 1967 (U)
(h) "Calibration of the ARTEIS Source and Receiving Array on the Mission Capistrano", M. Flato, Acoustics Div., NRL Memo Report 2712, Dec 1973 (U)
(i) "Theoretical Interaction Computations for Transducer Arrays, Including the Effects of Several Different Types of Electrical Terminal Connections", R.V. Baier, Sound Division, NRL Report 6314, 7 October 1965 (U)
(j) "Project ARTEMIS Acoustic Source Summary Report", NRL Report 6535, September 1967 (U)

1. References (a) thru (j) are a series of reports on Project ARTEMIS Reports by the Sound Division that have previously been declassified.

2. The technology and equipment of reference (a) have long been superseded. The current value of these papers is historical

3. Based on the above, it is recommended that reference (a) be available with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
NRL Code 7103

CONCUR:

Edward R. Franchi 1/23/2004

E.R. Franchi Date
Superintendent, Acoustics Division

CONCUR:

Tina Smallwood 1/28/04

Tina Smallwood Date
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